Evaluation of coking properties bituminous medium volatile coal, Batu Ayau Formation, Kutai Basin, Central Kalimantan

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Abstract. Selected coal samples of Batu Ayau formation in Murung Raya, Central Kalimantan, Indonesia were analyzed in order to evaluate its coking properties for metallurgical propose. The samples from an active coal mine were collected using the channel sampling method and analyzed for proximate and ultimate coal analysis, maceral analysis, CSN, fluidity, FTIR and HGI analysis. The results indicated that the coals are classified into medium volatile bituminous in rank, based on 70.73% of fix carbon, 26.77 % of volatile matter, 1.06% vitrinite reflectance and FTIR analysis. In terms of petrographic, the coals are characterized by 97% dominant vitrinite group while inertinite and liptinite are only present in a small amount. The ultimate coal analysis shows the 85.72 % carbon content, 0.51% total sulfur content and 0.013% phosphorus. The resultant of CSN test showed value 9 and the maximum fluidity value is 1092 ddpm while HGI indicated value 97 as result. Therefore, medium volatile bituminous coal of Batu Ayau, which met the present testing as good quality coking coal, is suitable to be used as the material to make high-quality metallurgical coke for the blast furnace.

Keywords: bituminous coal, medium volatile, coking coal, metallurgical coke, Kutai Basin.

1. Introduction

Coal, in general, can be classified as caking and non-caking type. Caking coals are coals that pass through a plastic state upon heating in which they soften, swell and re-solidify into a coherent carbonaceous matrix; while non-caking coals do not become plastic when heated and produce a weakly coherent char residue [1]. Caking coal, also known as coking coals, is strong caking coal that exhibits characteristics which make them suitable for the conversion into metallurgical and other industrial cokes [2]. Meanwhile, non-caking coal, commonly known as thermal or steam coal, is primarily used in power plants or power generating stations, which is used to generate energy or electricity.

Briefly, coking coal is a hard coal with the quality that allows the production of coke to be suitable for supporting a blast furnace charge. On the other hand, different from coking coal, non-coking coal, also commonly known as thermal coal or steam coal [3], is all other hard coals which are not classified as coking coals. These also include recovered slurries, middlings, and other low-grade coal products which are not further classified by type.

The ability of a coal to melt upon heating and form a coherent residue on cooling is defined as caking - an essential prerequisite for a coking coal that should cake or fuse when heated. Coals that are in lower rank, such as lignite, or in a higher rank, such as anthracites, do not cake, therefore they are not capable of forming coke. Several properties of coals are measured to identify the appropriate coking coals, including swelling, fluidity, maceral composition and vitrinite reflectance [4].

The coke quality is influenced by coal rank, composition, mineral content and caking properties. Bituminous coals class of high, medium and low volatile rank usually possess these properties. In general, there are several types of coking coals: premium hard coking coal, standard hard coking coal, semi-hard or semi-soft coking coal, and low or high volatile pulverized coal injection (PCI).

This research aims to evaluate the coal characteristics in the research location which is located in the Batu Ayau Formation of Upper Kutai Basin based on its coking properties. The analyzed coal sample in this research is taken from PT. Asmin Koalindo Tuhup in Murung Raya District, Central Kalimantan Province.

2. Geological Setting

2.1. Physiography
The research was conducted on Kohong area, Murung Raya district, Central Kalimantan Province with Barito Basin and Upper Kutai Basin as the economical basins. Physiographically, this area abuts on Mangkalihat High, Bengalon fault zone and Sangkulirang fault zone. In the south, this area is bounded to Barito Basin on Adang Fault Zone which serves as basin axis zone since the Late Paleogene Period until now (Figure 1). This basin is bordered by Central Kalimantan Range which is known as Kuching Orogenesis Complex (in the form of elevated and deformed limestone meta-sediment) in the west and Makassar Straits in the east.

Kutai Basin was generated by the rifting process (rift basin) happened in Middle Eocene which involves the rifting of Northern Makassar Straits and Sulawesi Sea [5]. During the Middle Cretaceous until Early Eocene, Borneo was a place where the collision with micro-continent, island arc, oceanic plate trap, and granite intrusion happens and it formed the bedrock of Kutai Basin's base. The sedimentation in the Kutai Basin is divided into two: Paleogene sediment which was transgressive, and Neogene sedimentation phase which was regressive.

Further, Kutai Basin can also be divided into two parts or sub-basins: Upper Kutai (sub) Basin, and Lower Kutai (sub-)Basin. Located on the northwestern, the Upper Kutai Basin is an area which was uplifted because of the tectonic process in Lower Miocene. Meanwhile, Lower Kutai Basin is located in the eastern part. Lower Kutai Basin is better known for its Neogene sediments compared to other sediment rifts during the Palaeogene which is the depocentre on the Upper Kutai Basin. The rifts were formed during the Palaeogene were inverted and eroded during the Neogene [5].

2.2. Geological Structure and Stratigraphy
The tectonic activity in this region began in Mesozoic with the emergence of granite, granodiorite, diorite, and gabbro in Busang complex which was followed by the emergence of rocks of Kalase volcano and sediment of Selangkai group in Late Cretaceous. The activity of volcanoes in Early and Middle Cretaceous begot Nyaan volcano rocks. Further, Haloq Formation, the inseparable Haloq and Batu Kelau Formation, Batu Ayau Formation and Tanjung Formation were formed on the Barito Basin and Mahakam headwater in the Late Eocene. These formations were covered in sync with Ujohbilang Formation since The Oligocene and, at the same time, Tuyu Formation were formed in the Kutai Basin. From Late Oligocene until Early Miocene, Berai Formation, Montalat Formation, Jangkan Formation, Karamuan Formation and Puruk Cahu Formation which is followed by Malasan volcano activity are formed; all of which overlapped the Ujohbilang Formation. Meanwhile, in the same epoch, Sintang intrusives happened [7] (Figure 2).
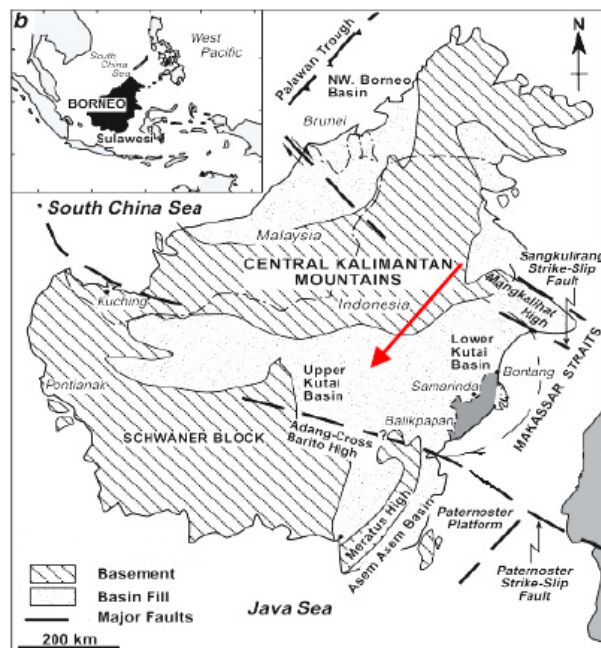
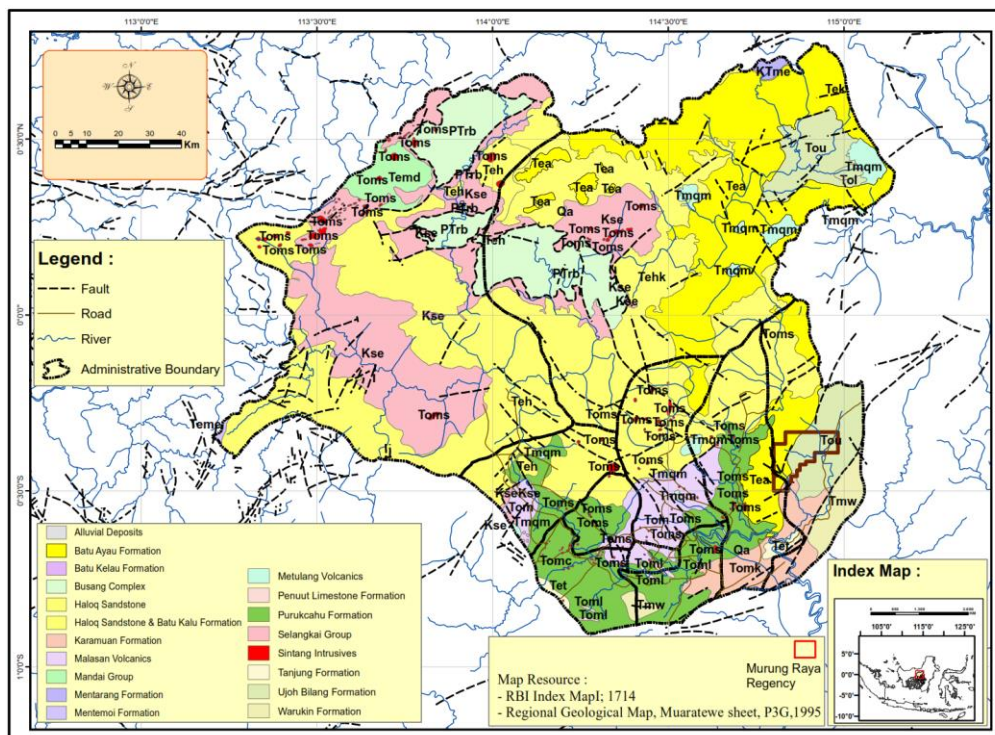**Figure 1.** The Geology of Borneo (Modified from [6])

Figure 2. Regional geological map of Murung Raya

In the Middle Miocene, Wahau Formation and Kelinjau Formation which inconsistently overlapped the Berai, Montalat, Jangkan, Karamuan and Purukcahu Formation were formed in the Barito Basin. Meanwhile, the sedimentation of Pulubalang Formation which was followed by Meragoh Volcano activity occurred in the Kutai Basin.

In the Late Miocene, Balikpapan Formation was formed in the Kutai Basin. Whereas, in Late Miocene until Quarter, the activities Metulang and Bandang Volcanoes happened in Barito Basin, and in Kutai Basin, Kampung Baru Formation was formed there [7].

Nonetheless, the dominant geology structure of Kutai Basin is the folds and faults which mostly strike NE-SW and sub-parallel to the east coastline of Borneo Island with the deformation occurs less intensive on the offshore areas [8] (Figure 3).

The structure development in Middle Miocene until Quarter is shown through the thin sedimentation on the top of the structure, whereas in the western part of Kutai Basin which was lifted shows the regional scaled structure in several places.
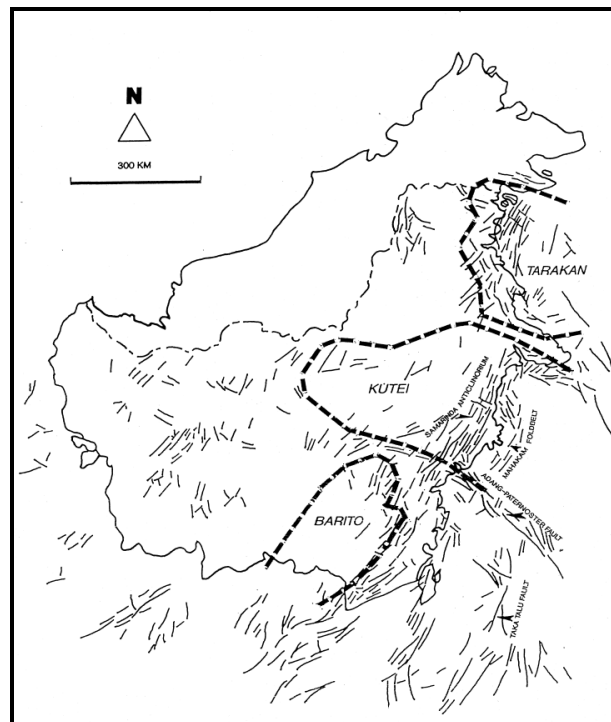

Figure 3. The general direction pattern of Borneo geological structure [8]

3. Coal Geology Murung Raya Area.

The common coal-bearing formations in Central Borneo are Warukin Formation, Tanjung Formation, Montalat Formation, and Batu Ayau Formation. The coal with the bituminous rank which has a potential as a coking coal is usually found in the middle and bottom of Tanjung Formation and in the bottom of Batu Ayau Formation [9]. In Murung Raya, the coal-bearing formations are Puruk Cahu Formation, Karamuan Formation, and Batu Ayau Formation.

The sampling location of this research is located on the eastern Murung Raya (Figure. 4), with the coal-bearing formation is Batu Ayau Formation (Tea). The lithology which composes Batu Ayau Formation in this area is composed of sandstone, mudstone, rocks, usually carbon, coal infix local and lignite and deposited over Batu Kelau Formation, this formation is Late Eocene and deposited in the shallow open-ocean environment [7] (Figure. 5).
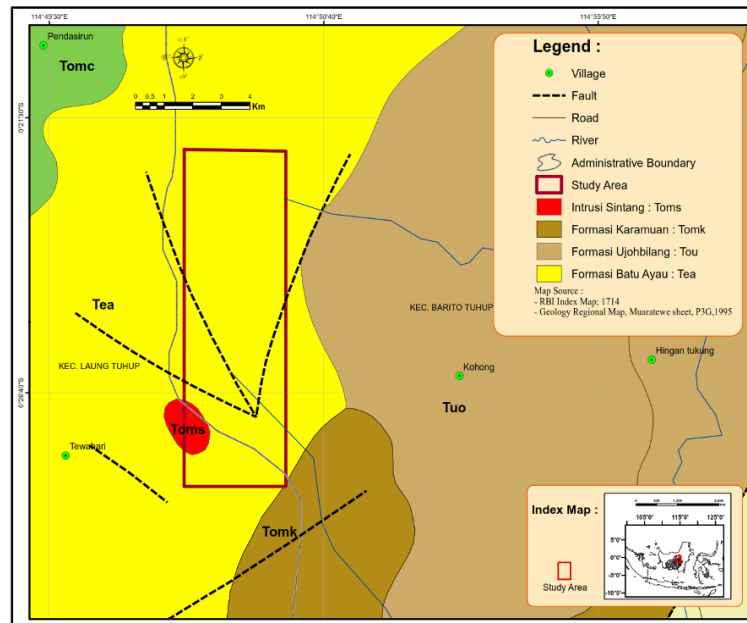
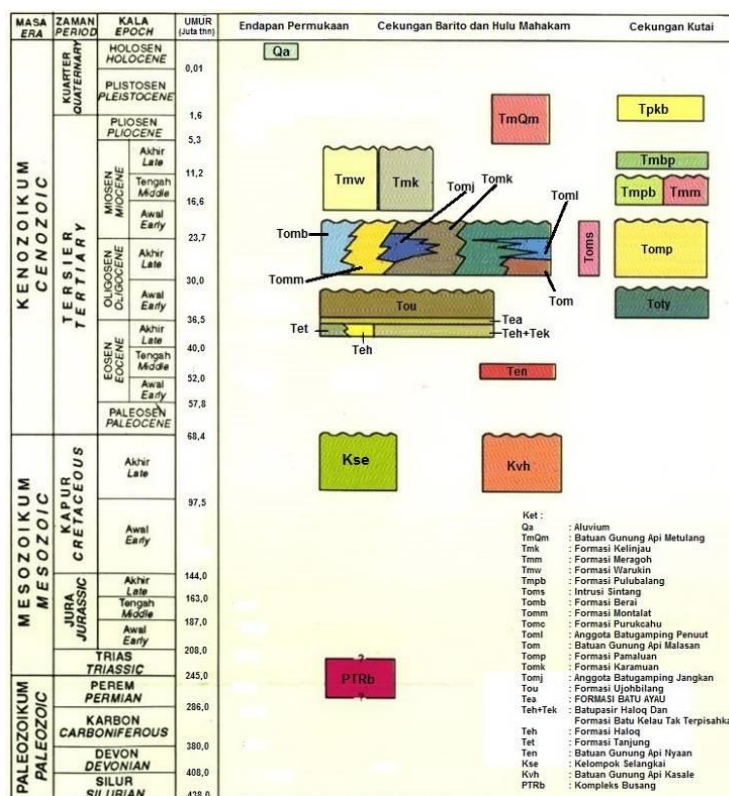**Figure 4.** Regional geological map of the research area (Modified from [7]).

Figure 5. Stratigraphy unit correlation of the research area [7]

4. Research Methods

4.1. Fieldwork

The coal sample for this research was taken from an active mine of PT. Asmin Koalindo Tuhup in Kohong area (Figure. 6). In the research area, the coal has different thickness ranging from between 0.6 to 2.11 meter and has smooth glossy black surface with calorific value (adb) 8300 cal/gr [10]. The

sampling method was channel sampling method ply by ply. The method of channel ply sampling/ply by ply is the best method for sampling in coal seams because the coarse coal layer is homogenous throughout its thickness [11]. Sampling method by channel ply sampling/ply by ply was done from the roof to the floor by dividing the layer into several sub-sections (Figure. 7).
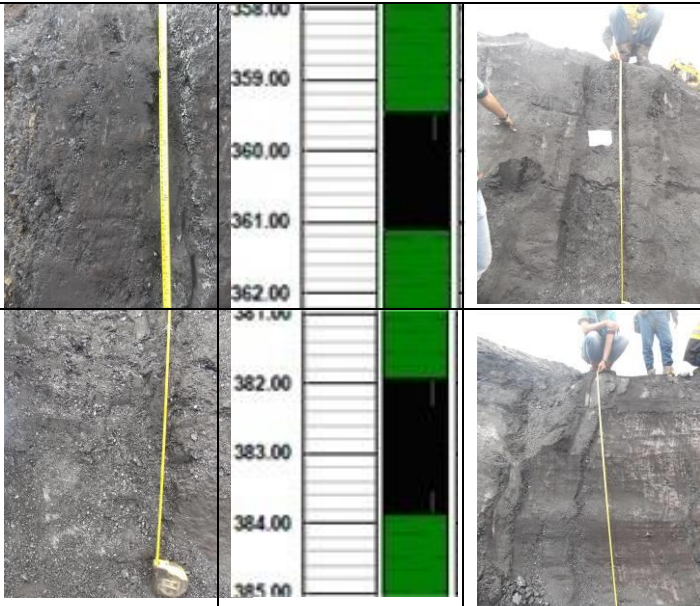
Code	Description	Lithotype			
K.39	Bright, black, brittle, frequently with fissures	Vitrain			
K.41	Bright, black, brittle, frequently with fissures	Vitrain			

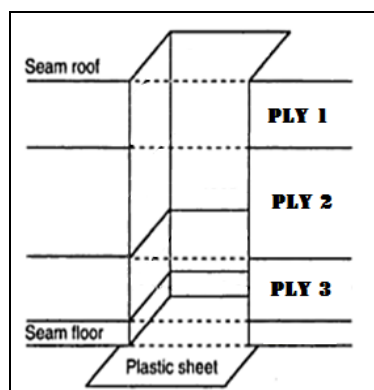**Figure 6.** The coals of the research area

Figure 7. Channel sampling procedure with channel ply sampling/ply by ply (modified from [11])

4.2. Laboratory Analysis

Coal proximate and ultimate analyses conducted on coal samples to determine the parameters of coal qualities. Proximate analyses include: inherent moisture-IM (ASTM D. 3173), ash content (ASTM D. 3174), volatile matter-VM ((ASTM D. 3175), fixed carbon (ASTM D. 3172) and total sulfur (ASTM D. 4239) while the ultimate analysis includes elements of coal such as carbon/C (ASTM D. 5373), hydrogen/H (ASTM D. 5373), nitrogen/N (ASTM D.5373) and oxygen/O (ASTM D.3176). FTIR analysis conduct with ASTM D. 6348.

Some other tests were also conducted to determine the coal coking properties, including Crucible Swelling Number/CSN test to find out Free swelling Index value ((AS 1038.12.1) for determining the swelling properties of coal when heated in a covered crucible, Gieseler Plastometer (AS 1038.12.4.1) to measure the plastic behavior of coal when heated under prescribed conditions, coal maceral analysis

(AS 2856.1; AS 2856.2.) and Hardgrove Grindability Index /HGI (AS1038.20) to measure the grindability of coal.

5. Result and Discussion
5.1. Coal Rank and Quality

Coal samples analysis result on air-dried basis shows Inherent Moisture (IM): 0.91%, volatile matter (VM): 26.77% and Fixed Carbon 70.73% (see Table 1). The inorganic geochemical composition consists of 1.44% ash content and total Sulphur of 0.51%. Ultimate analysis of coal on air-dried basis showed the Percentage of Carbon content (C) reaches 85.72%, Hydrogen (H) 5.25% and Oxygen (O) 5.11% (see Table 2), indicating that Batu Ayau Formation coal is classified into medium volatile bituminous coal type (ASTM Coal Classification).

In the spectra of the samples (Figure. 8), it is possible to observe characteristic bands of aliphatic groups. Prominent aliphatic C– H stretch was revealed in the 3000–2700 cm^{-1} zone. Generally, the examination of the 2800 to 3000 cm^{-1} zone revealed a progressive decrease in aliphatic hydrogen content up to the stage of bituminous coal [12]. In the aliphatic C–H bend region (1450 cm^{-1}), the absorbances are also the highest in low-rank coals and decrease with rank. The distribution of out-of-plane aromatic C–H in the 900–700 cm^{-1} range is also modified during maturation. Its absorbance increases with rank. This result indicates that aromaticity increases with rank, which agrees with many previous works [13-16].

From low-rank to high-rank coals there is a decrease in the intensity of the ~1600^{-1} cm band, which is assigned to an aromatic ring (C=C) stretch. This band is very intense in the low-rank coals but relatively weak in the high-rank coals, which are supposed to contain more aromatic material. This phenomenon has been discussed by Painter et al. [17]. They concluded that the absorbance is enhanced by the presence of phenolic groups or may be the result of a linkage of aromatic entities by methylene and possibly ether bridges. In low-rank coal, there is also an adsorption near 1580 cm^{-1} due to COO-groups. The absence occurrence of the carbonyl or carboxyl groups at around 1650^{-1} cm should be noted as well. The decrease of absorbance in the 1600 cm band is probably a consequence of the loss of phenolic O–H with rank as also observed by [18] than by the change of aromatic ring content.
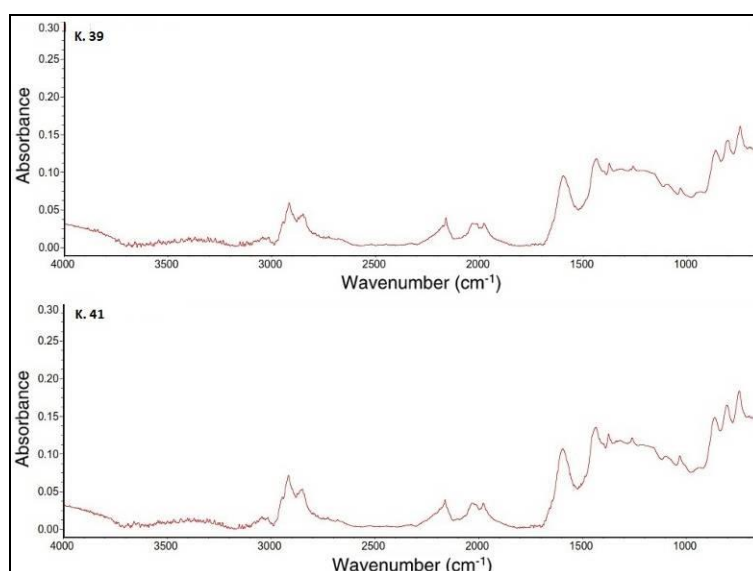
Coal samples analysis on physically properties shows result as follows: Crucible Swelling Number (CSN) is 9; Mean maximum vitrinite reflectance 1.06% which dominant maceral were vitrinite group (97%) while inertinite (1.4%) and liptinite (0.4%) are only present in small amount; Geisler Maximum fluidity: 1092 ddpm; Hardgrove grindability Index (HGI): 97 and phosphorus, which is calculation from XRF data shows the value of 0.013%.

Table 1. Proximate analysis of coal

Sample	Moisture in air % adb	Ash % adb	Volatile Matter % adb	Fixed Carbon % adb	RANK
K.39.T.01	1,03	1,94	27,31	69,72	Bituminous medium volatile
K.39.M.01	1,18	1,23	27,86	69,73	Bituminous medium volatile
K.39.B.01	1,11	1,11	27,97	69,81	Bituminous medium volatile
K.41.T.01	0,9	0,93	26,21	71,96	Bituminous medium volatile
K.41.M.01	1,01	2,57	25,45	70,97	Bituminous medium volatile
K.41.B.01	1,11	0,86	25,82	72,21	Bituminous medium volatile
Average	1,06	1,44	26,77	70,73	

Table 2. Ultimate analysis of coal

Sample marks	Carbon % adb	Hydrogen % adb	Nitrogen % adb	Total sulfur % adb	Oxygen % adb	O/C
K.39.T.01	84,77	5,22	1,89	0,54	5,64	0,07
K.39.M.01	85,78	5,35	1,95	.0,45	5,24	0,06
K.39.B.01	86,57	5,28	1,96	0,55	4,53	0,05
K.41.T.01	86,63	5,31	1,84	0,82	4,47	0,05
K.41.M.01	83,94	5,06	1,81	0,59	6,03	0,07
K.41.B.01	86,63	5,3	1,93	0,56	4,72	0,05
Average	85,72	5,25	1,90	0,51	5,11	0,06

Figure 8. FTIR spectra of studied coal

5.2. Evaluation on coal coking properties

Batu Ayau Formation coal samples analysis on coking properties showed value 88.20% carbon content (dry mineral matter basis), CSN value 9 and 1092 ddpm fluidity, Hardgrove grindability Index (HGI) 97, 0.51% total sulfur, 1.44% ash content, 0.013% phosphorus and volatile matter (dry mineral matter basis) value 27.24% indicated, medium volatile bituminous coal of Batu Ayau formation are good quality coking coal and suitable to be used as a single raw material to produce high-quality metallurgical coke for blast furnace and consider as a prime coking coal.

Considering maceral composition, the coal from the research area does not exhibit the ideal condition among its maceral group components despite the fact of having Mean Maximum Vitrinite Reflectance 1.06% which is within the ideal range of the best quality coking coal. Vitrinite group 97% (see table 3) becomes the most dominant maceral group compare to the inertinite group (1.4%) and liptinite group (0.4%). This becomes the only parameter that is not ideal for the coal from the research area to be directly used as single raw material in which the carbon-forming coal maceral characteristic in coke is also a controller. In the coke reaction in the furnace, the isotropic carbon on coke, formed from reactive maceral on coal carbonization the coking will be more reactive to CO_2 compared to the anisotropic carbon [19]. It affects to decreasing of CRI (Coke Reactivity Index) value which is one of the two main parameters of coke quality aside CSR (coke strength after reaction).

The lack in these maceral compositions, on the other hand, turns into a benefit and main additional value for medium volatile bituminous coal of Batu Ayau Formation to be used as a coking coal, where the fluidity value and Free Swelling Index value are very high yet the ash content, as well as the sulfur value, is low. The coal can be blended with rich bituminous inertinite in which the selling value is lower in the market to fulfill the assessment parameter as premium hard coking coal on various qualification and standard. Low volatile coal in the metallurgical industries is mostly not used as a sole ingredient but as a mixture with the percentage of 25-30 wt % components in coal blending [20].

Table 3. Maceral composition of coal samples

GROUP	VOLUME (%)	SUBGROUP	MACERAL	VOLUME (%)
VITRINITE	97	Telovitrinite	Telocollinite	95,4
		Detrovitrinite	Desmocollinite	1,6
LIPTINITE	0,4		Sporinite	0,2
			Cutinite	0,2
INERTINITE	1,4	Telo-inertinite	Funginite	1,4
MINERAL	1,2			

6. Conclusions

Selected coals from Batu Ayau Formation, Upper Kutai Basin have a high carbon content, fixed carbon, and medium volatile matter and classify as bituminous medium volatile coal. Maceral composition of coals have abundance vitrinite content, but low on inertinite and liptinite percentage, indicated the coal occur on high geothermal gradient or close to the intrusive body [21].

Some parameters used to measure the coals as coking coal for raw material to make coke for steel making in blast furnaces, including CSN, Fluidity, Vitrinite reflectance, carbon content, volatile matter content, ash and total sulfur, satisfying the present tests and indicated the coal have good quality as coking coal and suitable as single raw material to produce high-quality metallurgical coke, besides lack of inertinite content. However, the coals can be blended with bituminous inertinite rich to accept premium hard coking coal on various qualification and standard.

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